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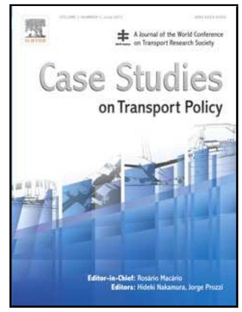

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Authors: Meng Xu, Susan Grant-Muller, Ziyou Gao

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Implementation Effects and Integration evaluation of a Selection of Transport Management Measures in Beijing

Meng Xu

State Key Laboratory of Rail Traffic Control and Safety
Beijing Jiaotong University
No. 3 of Shangyuan Residence, Haidian District, Beijing, 100044, China
Tel: +86-10-5168-7070
Fax: +86-10-5168-7127
Email: mengxu@bjtu.edu.cn

Susan Grant-Muller

Institute for Transport Studies
University of Leeds
34-40 University Road, LS2 9JT Leeds, UK
Tel: +44 (0)113 34 36618
E-mail: s.m.grant_muller@leeds.ac.uk

Ziyou Gao

State Key Laboratory of Rail Traffic Control and Safety
Beijing Jiaotong University
No. 3 of Shangyuan Residence, Haidian District, Beijing, 100044, China
Tel: +86-10-5168-8193
E-mail: zygao@bjtu.edu.cn

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Highlights

- A qualitative evaluation framework covers equity, efficiency and transport sustainability
- Transport management measures that were introduced following the Beijing 2008 Olympic Games
- Effects of the measures with respect to growth in vehicle and trip numbers

Abstract

With the serious urban transport challenges that rapid motorization and growth in travel demand for the city of Beijing have brought, the design and implementation of efficient and equitable urban transport polices has become essential to achieve sustainable development targets. This paper investigates a selection of transport management measures that were introduced following the Beijing 2008 Olympic and Paralympic Games. These include priority development of mass transit systems, private car ownership measures, a staggered rush hour plan, modified charging policies for parking and car restrictions based on license plate numbers. Effects of these measures with respect to growth in vehicle and trip numbers are summarized, then qualitatively evaluated within a proposed framework that covers in one dimension equity and efficiency and in another, social, economic and environmental aspects of transport sustainability. The evaluation process is intended to firstly shed light on the effects of transport management measures according to different sustainability dimensions and secondly to support policymakers involved in the practical design of future transport management measures for Beijing and similar city contexts.

Keywords: Transport policy; Sustainability; Equity; Economic Efficiency; Beijing

1. Introduction

Beijing as the major political, commercial and financial centre of China has a high population density. It has a distinctive lay-out comprising multiple outer ring roads with inter-ring road route connections. The overall pattern of development has been characterised by rapid population growth over several decades, rapid economic growth and rapid motorization. The traffic pressures in the city are evident to both passengers and drivers and a series of tactical measures have been carried out in response, and the issue of how to relieve traffic congestion and develop an efficient transport system in Beijing has recently received attention worldwide.

During the Beijing 2008 Olympic and Paralympic Games, both travellers and citizens benefitted from the relatively uncongested roads and clean air in the city that resulted from a series of regulatory transport policies and tactics. However, traffic congestion and air quality deteriorated quickly afterwards and the benefits were lost. In 2009, a plan was published to develop ‘humanistic, technology rich and green transport systems’ (PGBM, 2009). The plan focuses on a more ‘human-oriented’ development of the transport system, including coordination with the historic and cultural characteristics of the city, a more harmonious traffic environment, improvements to the level of service and enhancements to the administration of urban services. The essence of the new plan was therefore the development of a sustainable transportation system for the city of Beijing.

In this paper, we firstly analyse recent problems with the Beijing transport system and review the transport management measures that have been introduced. To evaluate these measures post-hoc, we propose a new framework based on efficiency and equity in one dimension and broader sustainability aspects on another. Evaluating these measures along any one of these dimensions is challenging and yet policy makers should ideally be looking across the dimensions to get a more holistic picture of the impacts of policy measures. To undertake this for the framework using a fully quantitative approach brings both theoretical and conceptual issues to the fore, here we propose an approach taking quantitative indicators into a simple qualitative and holistic framework. The novelty is that whilst equity and efficiency may be either excluded or only implicitly included in some sustainability indicators, we propose explicit treatment of both here. The structure of the remainder of the paper is as follows. Section 2 presents a literature review of sustainable transport research concerning Beijing and summarizes five typical transport management measures. Section 3 then introduces the five principal transport management policies for the mitigation of congestion introduced in Beijing following the 2008 Olympic and Paralympic Games. Following an initial impact analysis against eight types of travel behaviour characteristics to identify key drivers for change, this section also presents a quantitative summary of the effects of the transport management measures with respect to growth in both vehicles and trips. A qualitative post-hoc evaluation of the transport management policies using the proposed integration evaluation framework (and in the wider context for Beijing) is presented in Section 4, followed by conclusions to the paper.

2. Literature Review

Transport management policies play an important role in sustainable transport development. The development of a sustainable transport system has favoured multiple solutions, for example, institutional reforms (Hull, 2008), land use changes (Curtis, 2008), policy transfer (Marsden and Stead, 2011), energy (Figueroa and Ribeiro, 2013) and carbon reduction (Marsden, et al., 2014). Besides some basic issues related to the definition, evaluation and implementation of sustainable transport development (Litman and Burwell, 2006; Marsden and Snell, 2009; Marsden et al., 2010), research into policies for the development of sustainable transportation has been of considerable interest to practitioners. Specific examples include the issue of sustainable transport in Europe and North America (Greene and Wegener, 1997), the sustainable urban transport issues pertinent to typical Asian cities (Ieda, 2010), the development of sustainable cities in Singapore (Phang, 2003), the interaction of factors influencing transport sustainability for both passenger and freight transport (Richardson, 2005) and the importance of an appropriate regulatory framework and effective mechanisms of enforcement for sustainable urban transport systems in developing countries (Sohail et al., 2006). The latter was based on case studies in three cities and highlighted the critical importance of communication and co-ordination between stakeholders (i.e. transport users, providers and regulators) for effective regulation, and the relationship between sustainable transportation, infrastructure planning and implementation (Short and Kopp, 2005; Sand, 2012).

This established body of transport policy research has resulted in new policy science approaches, international case studies and local evidence against which potential measures for a more sustainable transport system in Beijing can be studied. Recently there have been studies concerning transport management and some specific urban transport problems in Beijing or in other cities of China. These have demonstrated how different policies have played a major role in the development of the transport system. For example, Ahmed et al. (2008) focused on the impact of existing strategies on equity in the development of transport systems in Beijing and Karachi, proposing strategies for the development of sustainable and equitable urban transport systems. Mao and Chen (2001) presented a sustainability analysis of typical policies implemented in China including Beijing. Creutzig and He (2009) demonstrated the synergies that joint demand and supply-side policies could provide, based on an analysis of a policy based on number plate constraint introduced in Beijing during the 2008 Olympics Games. Han et.al (2010) discussed efficiency based on road space rationing schemes implemented in Beijing. Wang (2010) explored four potentially contentious urban transport policies (congestion pricing, new plate quotas, driving bans and park-and-ride) in order to understand the likely efficiency and distributional consequences in China. Xu et al. (2010) reviewed the evolution of public transport systems in Beijing municipality in order to understand the importance of governance on public transport development. Li et al. (2010) studied travel patterns during the 2008 Olympic Games. Their Beijing Olympic transport model (based on activity-chain forecasting) led to proposals for demand management measures. Recent transport policies studies in Beijing also include Wang and Yuan (2013), Chang (2014), Sun et al. (2014), and Xu et al. (2015).

Studies of transport management measures and specific urban transport problems in Beijing lead us to focus on some typical transport management measures and how these measures in Beijing compare against other experiences. Alongside continued development of transport infrastructure in Beijing, some of the different traffic management measures that have been proposed for the municipality following the Olympic Games include: Prioritisation of mass transit systems (S1); Private car ownership measures (S2); Staggered peak-hour planning (S3); Parking charge policies (S4); Traffic restrictions based on the last digit of license plate numbers (S5). Generally, all these five management measures can be called "command-and-control" measures, as they have been introduced using government regulations and are mandatory for travellers. Although from an economic perspective these measures fail to achieve an efficient market outcome, the presence of political constraints makes them the preferred option with respect to feasibility and effectiveness. Table 1 presents recent studies that have investigated five typical transport measures in Beijing, and reviews some major findings of these measures with respect to different study areas and major findings. These are outlined below and a summary is given in Table 1, whilst further details can be found in Xu et al. (2015).

Whilst previous international research has considered the development of an advanced urban transport system in Beijing, it has been largely focused on the design and development of local transport. Relatively little research has taken place into understanding the impacts and potential of transport management policies introduced in Beijing. A less well explored topic for Beijing is the evaluation of transport management measures under a multi-criteria framework. Multi-criteria evaluation plays an important role in transport policy decision support, but is particularly challenging in the case of Beijing due to the rapid pattern of development (in terms of population growth, economic growth and motorization), alongside the application of potentially competing evaluation criteria. In this paper, we focus on transport management measures in the period following the Beijing 2008 Olympics and Paralympic Games, considering in particular the needs and characteristics of the Beijing urban transport system within the context of a strategic level, qualitative evaluation of transport management policies.

3. Implementation Effects: Summary for Beijing Municipality

3.1 An initial impact investigation for S1-S5

There are different transportation demand management (TDM) strategies, as concluded in the online TDM Encyclopedia by Victoria Transport Policy Institute (VTPI, 2014), which is important to increase understanding and implementation of TDM. The various studies of the five transport management measures summarized in Table 1 underpin the synthesis of implementation targets for the outline schemes (when applied in the municipality of Beijing). Further, Table 2 presents their expected impacts on travel behaviour. These impacts are first briefly described below with respect to the following eight types of travel behaviour characteristics proposed by Litman (2013):

I1: vehicle ownership: travellers changing the number of vehicles they own;

I2: vehicle type: motorist choosing a different vehicle (more fuel efficient, alternative fuel, etc.);

I3: route change: travellers shift travel route;

I4: time change: peak to off-peak shift;

I5: mode shift: travellers shift to another mode;

I6: destination change: motorists shift trip to alternative destination;

I7: trip generation: people take fewer trips in total (including consolidating trips);

I8: land use changes: changes in location decisions, such as where to live and work.

Mass transit (or public transport (PT), including subway, bus, bicycle, taxi, etc.) is one of the sustainable urban transport modes and a potential route to mitigate some of the transport problems in many cities internationally. Beijing policymakers have decided to prioritise the development of mass transit as an effective way to increase transport efficiency and mitigate congestion. The key to these measures included legislation to accelerate the construction of a comprehensive public transport system, a focus on the development of subways and large capacity rapid transit systems, an aspiration to develop as a 'public-transport city' with an attractive, fast and convenient mass transit service, and to mitigate traffic congestion based on PT and "1-1-2" plans for 2015. The '1-1-2' plan means that it takes no more than one hour (on average) to travel between any two places in central Beijing zone, and no more than one hour from the remotest satellite town to the nearest point on the Fifth Ring Road. Travel time will take two hours or less from Beijing to the so-called "Bohai Bay Economy Rim (including Tianjin, Tangshan and other major cities nearby)" (Li, 2009). The proposed prioritisation of new mass transit systems (S1) is most likely to affect travellers' route choice (I3) and mode choice (I5) directly, and further affect vehicle ownership (I1). More people are likely to choose PT and vehicle ownership may reduce with attractive PT services. This measure will also influence travellers' destination choice (I6) and their decisions on their living and working place as an indirect impact (I7-I8).

In addition to implementations of license plate restrictions in Beijing, several other cities in China have also adopted this measure, including Shanghai, Guiyang, Guangzhou, Shijiazhuang, Tianjing and Hangzhou. This measure, however, has implemented with different policy designs, e.g., Shanghai with the auction mechanism, Guangzhou began restricting car purchases using a system with hybrid auction and lottery components. In 2011, Beijing became the first city to allocate vehicle license plates using a lottery (Yang et al., 2014). Under the scheme, those wishing to purchase a new car have to wait for the quota from a license plate 'lottery' scheme first. The private car ownership controls (S2) are most likely to affect vehicle ownership directly (I1) and further affect trip generation (I7), changes in location decisions (I8), travellers' mode (I5), destination (I6), and route choice (I3) indirectly. It is noted that S2 also can affect motorists' choice of vehicle types indirectly (I2), considering that an electric vehicle has higher odds of winning a license plate compared to a petrol car (http://www.bloomberg.com/news/articles/2014-02-26/beijing-license-plate-lottery-sees-few-takers-for-electric-cars). Furthermore, to encourage more residents to switch to electric cars, the city offered electric car incentives and privileges, such as the exemption of electric cars from restrictions on the number of vehicles during the rush hour and the freedom for qualified applicants to buy electric cars outside the lottery scheme from 2016. In contrast, the odds of winning a license plate for a petrol car are low. 90,000 quotas in total were made available for 2016, which will be assigned within six allocations. By the close of 8th Feb., 2016, the number of applications reached 2,589,995, indicating a low chance of success (www.bjhjyd.gov.cn).

The PGBM decided to implement a staggered rush hour plan (S3) in 2010. The working day was adjusted to start at 9:00am instead of 8:30am and to end at 6:00pm instead of 5:30pm, and around 0.81 million municipal government employees have been involved in the scheme. The implementation of S3 in Beijing was expected to affect the traveller's time schedule (I4), route choice (I3) and mode choice (I5) for a trip. The new charging policies for parking (S4), which have specifications for three specific areas and time variations in Beijing, was expected to discourage the ownership and use of private cars, thereby influencing vehicle ownership (I1), model shift (I5), destination changes (I6) and trip generation (I7).

Finally, traffic restrictions based on the last digits of license plate numbers (S5) started from a temporary road space rationing policy during the Olympic Games, mitigating congestion and improving air quality. Following the success of the license plate policy, the BTMB introduced more formal regulation (i.e. S5) by issuing a series of notices for traffic restrictions based on the last digit of the license plate numbers. Combined with other measures (S1-S4), this has influence mode shift (I5) (shifting private car use to PT use or cancel trips or changes in living and employment location decisions), and thereby affected trip generation (I7) and land use changes (I8).

The time distribution for the issue of the policies is shown in Figure 1. As can be seen, facing the transport challenges has brought an increase in measures implemented since 2008.

3.2 Vehicle growth

The fast growth in motorization in Beijing can be seen from Figure 2. The total number of private cars in Beijing has increased dramatically in the period from 2005-2010. According to BTMB statistics, it took 48 years to reach the first million vehicles in use. By 2003 and 2007, the second and third million vehicles were reached respectively, with a gap of just 3.9 years before the level of three million vehicles was reached. By the end of 2009 (a gap of just 2.5 years), more than four million vehicles (4.02 million) were registered and by 2012, a figure of 5.2 million vehicles was reached for Beijing municipality. With the introduction of S2 in late 2010, the growth of motorization decreased. Compared with the fast growth from 2005-2010, the number of private cars has only increased by 0.119 million (402.8-390.9=11.9) in 2011 to 0.164 million (419.2-402.8=16.4) in 2012. This is in contrast to the total number of vehicles, which increased by 0.174 million in 2011(498.3-480.9=17.4) to 0.217 million (520-498.3=21.7) in 2012.

3.3 Trips by mode

According to the Beijing Transport Annual Reports issued by BTRC (2005-2013), the numbers of average daily trips (Unit: Million person journeys per day) within the area of sixth ring road in different years are as shown in Column 2 of Table 3. The statistics for total average daily trips cover different travel modes i.e. road surface PT, subway, car, taxi, cycling and others but excluding walking. Columns 3 to 6 in Table 3 provides a breakdown of the number of average daily trips by road surface PT, subway, car and cycling for the year 2005 and from the year 2007 to 2012 (Unit: Million person journeys per day). Table 3 also shows the total population (Resident/Float population) for each year (Unit: million persons) in Column 7.

Based on the annual population and annual vehicle numbers given in Figure 2, we can calculate the average daily car trips (car trips from Column 5/ annual vehicle numbers, given in Figure 2) (Unit: daily number of journeys per car) and average daily trips (the total average daily trips/ population, from column 7) (unit: daily journeys per person), as shown in the final two columns in Table 3. As can be seen from the total daily trips by modes, road surface public transport trips and subway trips continue to increase alongside the population increase, whilst cycling trips decrease each year. Although the average number of daily trips per person increases each year (except in 2011), the average number of daily trips per car steadily decrease in total. The number of average daily trips per person has increased to 1.56 journeys per person in 2008 and 2009, compared with 1.31 journeys per person at the year of 2005 and 1.39 journeys per person at the year of 2007. The number of average daily car trips then decreased to 1.48 journeys per person in 2010, 1.42 in 2011 and 1.47 in 2012. These patterns are positive indications that these transport management measures generally had an impact on the reduction of car usage and person trips. It also needs to be noted that what these TDM measures attempt to influence is to curb the motorised travel, so that traffic congestion and energy resources are reduced, air quality is improved, and health and liveability of the city are increased, the reduction on the average number of daily trips per person is an indication of restricted mobility[1]. Moreover, although the positive indications to decline in the average number of daily trips per car, both the relative increases in number of total trips (50%) and car trips (67%) exceeded the increase in population (about 34%) witnessed between 2005 and 2012 from the aggregated analysis.

From the trips by mode given in Table 4, we can investigate the differences in average travel time and average travel distance in the morning peak hour and afternoon peak hour. These have been collated for road surface public transport (M1), subway (M2), car (M3) and cycling (4) for each year (2009-2011) from the Beijing Transport Annual Reports issued by BTRC (2009-2013). As noted in the annual reports, the travel modes (M1-M4) represent the main mode for a trip, and the average travel time for M1, M2 and M3, (given in Table 4 for peak hours) also includes the possible cycling travel time and/or walking time for a trip. Trip differences during the peak hours (see Table 4), indicate that the selected transport management measures had an impact in terms of peak hour trip mitigation. Comparing information on average travel distances at peak times in Table 4, road surface PT (M1) and cycling mode (M4) continue to increase, in comparison with the changes for the car mode (M3) and subway mode (M2) in the years 2009-2011. During the morning peak and evening peak, the average travel time for road surface public transport, subway and cycling have obviously decreased in comparison with a minor improvement in car trips. The case for the evening peak car trips are, in fact, worse than before.

Continuing the peak-period analysis, we can derive the average travel speed (ratio of average travel distance over average travel time) with respect to the morning peak and evening peak (unit: Km/hour), as given in Table 4. It is somewhat surprising that the speed for public transport (M1 and M2) is seen to be lower than for car mode (M3), especially for the subway (M2). There are probably a number of different reasons for this, but it may reflect the underlying statistics used in calculating the average travel time for a trip. These include the possible cycling travel time and/or walking time for a trip, as noted in the Beijing Transport Annual Reports (2009-2011).

4. Qualitative Evaluation: Sustainability vs Equity and Efficiency

[1] We owe this point to a reviewer of this paper.

Returning to the policy direction set out for Beijing, the 2009 plan promotes the goals of a 'humanistic, technology rich and green transport systems' (PGBM, www.beijing.gov.cn). An evaluation framework for the success of transport measures introduced in Beijing should therefore reflect forward direction and success in these dimensions. These three key dimensions have therefore formed the basis for the qualitative evaluation framework described in this section, summarised most succinctly as human impacts, efficiency impacts and sustainability impacts.

4.1 Sustainable aspects of transport management policies

As presented in the literature review in Section 2, the evaluation and implementation of sustainable transport development has received considerable attention. Transport systems exist to provide social and economic connections, and people quickly take up the opportunities offered by increased mobility (Schafer, 1998). The sustainable transport systems make a positive influence to the environmental, social and economic sustainability of the communities they serve. The Centre for Sustainable Transportation (CST) at the University of Winnipeg, in their document "Defining Sustainable Transportation" (see Page 5-6, http://cst.uwinnipeg.ca/documents/Defining_Sustainable_2005.pdf), presents a definition of a sustainable transport system as one that 'allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, considers equity within and between generations; is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise'. This CST definition therefore recognizes the social, economic and environmental aspects of transport sustainability, i.e., with respect to society, transport systems should therefore:

- (So1) Meet basic human needs for health, comfort, and convenience in ways that do not stress the social fabric
- (So2) Allow and support development at a human scale, and provide for a reasonable choice of transport modes, types of housing and community, and living styles
- (So3) Produce no more noise than is acceptable by communities

- (So4) Be safe for people and their property

With respect to the economy, transport systems should

- (Ec1) Provide cost-effective service and capacity
- (Ec2) Be financially affordable in each generation
- (Ec3) Support vibrant, sustainable economic activity

With respect to the environment, transport systems should:

- (En1) Make use of land in a way that has little or no impact on the integrity of ecosystems
- (En2)Use sparingly energy sources that are essentially not renewable or inexhaustible
- (En3) Use other resources that are renewable or inexhaustible, achieved in part through the reuse of items and the recycling of materials used in vehicles and infrastructure
- (En4)Produce no more emissions and waste than can be accommodated by the planet's restorative ability

These sustainability criteria form the basis for the sustainable transport dimension in the simple post-hoc evaluation approach proposed here, as mentioned in Xu et al. (2015), the five transport management measures (S1-S5) have focused on the elements of society and economy and as a result, further effective transport management policies oriented toward other aspects of sustainable transport still need to be considered for Beijing. Therefore, the sustainable transport dimension provides appropriate approach for the measures evaluation.

4.2 An assessment approach based on equity and efficiency factors

There are different perspectives for the assessment of transport management policies. Besides the sustainable transport dimension, we can investigate the equity and efficiency factors, see Thomopoulos and Grant-Muller (2013) for equity aspects, and Southworth et al. (2004); Moudon et al. (2005); Sullivan, et al. (2010) for efficiency aspects. Recently, Xu, Grant-Muller and Gao (2015) investigated the equity and efficiency factors of economic regulatory policies for expressway infrastructure in China.

a) Equity Principles

- EP1- Utilitarian policy principle

  Aims to maximise the net benefit for all regions impacted by transport management policies, disregarding the distribution of benefits

- EP2 – Equal shares policy principle

  Distributes an equal share of all benefits of transport management policies to all regions impacted

- EP3 – Rawlsian policy principle

  Distributes transport management policy benefits to the least advantaged regions until those reach the level of the most advantaged regions

- EP4 – Egalitarian policy principle

  Reduces pre-existing inequalities between regions by distributing all transport management policies benefits to the least advantaged regions

- EP5 – Minimum floor policy principle

  Distributes a minimum level benefits of transport management policies to all regions

- EP6 – Maximum range policy principle

  Sets a maximum range of benefits of transport management policies to be distributed to each region and distributes benefits to all regions respectively

b) Efficiency Targets

- ET1- Minimizing Cost

  Aims to minimise costs to achieve benefits for the transport management policies involving the economic, environmental, energy, human and operations aspects

- ET2- Maximizing Service Level

  Aims to maximized service level to improve transport efficiency from the economic, environmental, energy, human and operations side

Therefore, a combined framework is used utilising both equity and efficiency impacts. The framework explicitly considers equity and efficiency whilst other sustainability approaches also included explicitly.

4.3 Integration evaluation of the Transport Management Policies implemented in Beijing

Based on the evaluation framework given in Section 4.2, and combined with the social, economic and environmental aspects of transport sustainability (Section 4.1), we further discuss the characteristics of the five transport management measures (S1-S5) implemented in Beijing (as summarized in Table 2), within the integration evaluation framework, as shown in Table 5.

Comparing the traditionally computed single evaluation outcome (for example in the form of a Benefit: Cost Ratio, BCR) with the eleven sustainable transport criteria, or the six equity principles and the two efficiency targets, the integration evaluation framework provides for a more comprehensive representation of the scope and distribution of scheme impacts. It also allows for the possibility to identify compensating impact outcomes or 'trade-offs' to the different criteria of each transport policy. The inclusion of several principles (for example for equity) rather than a single measure, allows the possibility for different perspectives of this increasingly important impact to be captured. At present there isn't a single universally accepted approach to equity, so whilst the research and debate continue it is preferable to seek to accommodate the spectrum of possibilities in the framework. These factors underlie our proposal that this integration evaluation would provide an improved framework to evaluate applied transport management measures.

From the perspective of sustainable transport, policies (S1-S5) are focused on elements of society and the economy. As a result, more effective transport management policies oriented towards other aspects of sustainable transport still need to be considered for the city of Beijing. The priority development of a mass transit system (S1) is aligned with a sustainable transport system as it will limit carbon dioxide emissions arising from rapid development in the city. However, a more effective evaluation approach for the impacts of mass transit policies is needed to reflect the travel and structural characteristics of Beijing. Other transport management policies (S2-S4) are focused on reducing levels of activity and adjusting mode shares. These are expected to impact on social and economic factors rather than broader sustainability.

These policies can be further assessed according to a framework covering equity and efficiency, considering the important role of the equity and efficiency factors in state-of-the-art transport appraisal approaches. As mentioned in Section 4.2, the equity principles were drawn from Thomopoulos and Grant-Muller (2013), whereas for further details on the development of the efficiency factors, the reader can refer Sullivan et al. (2010).

In general, policies including S1, S3, S4 and S5 demonstrate a utilitarian policy principle (EP1) and cover efficiency targets, whilst S1 covers both the targets on efficiency, and policy S5 is focused on cost minimization, policies S3 and S4 emphasize service level maximization. The policies S1 and S2 also demonstrate a general equal shares policy principle (EP2) and policy S4 follows the Egalitarian policy principle (EP4). There is still a lack of regulation following a Rawlsian policy principle (EP3), the minimum floor policy principle (EP5) and the maximum range policy principle (EP6), however, more transport management policies are anticipated that may follow these principles.

The evaluation overall leaves issues for policymakers in considering future transport management policies that are appropriate for the characteristics of the city of Beijing. According to the definition of the equity and efficiency factors and the practical effects as shown in the Section 3, Table 5 can be applied to assess the five transport management measures applied in Beijing after 2008 with respect to different aspects of sustainability. The row consists of assessment indices covering equity principles and efficiency targets, and the column consists of the social, economic and environmental aspects for the transport sustainability definition. We use the subscript "+" to represent 'principle/target satisfied', the subscript "-" represents "principle/target not satisfied" and the notation "/" represents "not applicable" for the evaluation. For example, "$S1_{+,+}$" in the first cell reflects that the policy S1 satisfies the principle EP1 and the standard of So1, "$S1_{+,-}$"crossing EP1 and En3 reflects that the policy S1 satisfies the principle EP1, however, it does not satisfy the standard of En3; "$S3_{+,/}$" crossing EP1 and So2 reflects that the policy S3 satisfies the principle EP1, however, it does not apply to the standard of So2. Changes in quantitative indicators such as those shown in Tables 2 and 3 together with the underlying driver in the policy measure were used to determine the sign applied. Moreover, in order to preserve the low level detail for those readers who will be interested we still prefer to present our findings in table format. We have included the heat maps as given in Figure 3 in addition to the table 5 by way of broad summary. Noted that S5 does not shown in Figure 3 since it does satisfy two principles/standards simultaneously.

The overall process is summarised in Figure 4 below, whereby each step can be interpreted in the specific context and applied to a variety of schemes of different scale, according to the data that is collected by national/local practice. The framework is flexible in that at detailed level, different measures of sustainability may be chosen according to the focus of the schemes being studied – for example light rail schemes will generate different impacts and be monitored using different environmental data to urban city schemes concerned with reducing highway congestion.

5. Conclusion

In response to increasing travel demand, policymakers in Beijing have made, and continue to make, great efforts to propose and implement different policies for traffic congestion mitigation based on the particular characteristics of Beijing municipality. The development of these policies is against a backdrop of rapid transport infrastructure development to try to accommodate the demand by increasing supply. The high level and long term policy goal described at the outset of the paper reflected the aspiration that the traffic system should 1) have the person at the centre, 2) that it should capitalise on the efficiencies and modernity brought about by the most recent technologies and 3) that it should be sustainable.

These three key characteristics have formed the basis for the qualitative evaluation framework described here, summarised most succinctly as human impacts, efficiency impacts and sustainability impacts. Capturing these three policy characteristics separately in a flexible framework makes explicit the potential full range of impacts, the possible trade-offs between them and the overall extent to which the long term policy goals have been achieved. The framework proposed draws on indicators that have been previously developed, published and as such, accepted by the community, lending to their credibility and established nature. The novelty here is in the proposal to combine these in a single framework.

There are different dimensions to a human orientated approach, however the notion of equity is one which is core and forms the basis in evaluating the extent to which the development of the transport system achieved is ‘people focused’. The six equity principles established specifically in relation to evaluating transport systems in the literature have been adopted here. Whilst the policy statement elaborated efficiency aspects in terms of level of service, administration and a harmonious traffic environment, we have streamed these into the two main efficiency categories of service and cost. The policy statement was finally concerned with sustainability – not only environmental sustainability but also social and economic sustainability. This has been structured into the total of 11 sustainability criteria across these categories by drawing on the established state of the art in the literature.

The evaluation framework proposed therefore captures the essence of the policy vision for the Beijing transport system whilst reflecting established assessment criteria and promoting the disaggregate reporting of these. The disaggregate reporting structure supports the notion that there may be some balancing trade-offs between the different criteria but also indicates where there has been a greater or lesser focus with the measures introduced.

At a more detailed level, attention and analysis has been given here to the five specific measures that were introduced following the Beijing Olympic Games. These include priority development of mass transit systems, private car ownership control, a staggered rush hour plan, new charging policies for parking, and traffic restrictions based on the last digit of license plate numbers. A range of studies that concerned these five transport demand management measures were reviewed in Section 2. It was apparent from those studies that a number of unintended consequences has arisen with some real life implementations and in some cases these measures had been less than successful. In seeking to explore this, it was clear from the analysis against the eight drivers for behavioural change proposed by Litman (2013) that some of the management measures are expected to influence behaviour across the spectrum (for example private car ownership constraints) whilst some were more tightly focused on particular aspects of choice, such as the new working time schedule measure. This creates the prospect of intense (duplicated) pressure points on some aspects of travel choice where measures are introduced concurrently, potentially shifting the thresholds for behavioural change in other aspects and leading to some unexpected outcomes. As an overview of the 'bigger picture', the high level impacts arising from the introduction of the five traffic management measures in Beijing (specifically with respect to patterns of growth in vehicles and trips) are summarized in Section 3.

The transport management initiatives have been evaluated using the integrated evaluation framework comprising equity and efficiency in one dimension and sustainability in another. From the qualitative evaluation, the initiatives evaluated were targeted mainly towards the elements of society and economy. They demonstrate a utilitarian policy principle and cover efficiency targets. These measures still leave obvious gaps however, in satisfying other important principles listed in Table 5.

Whilst the proposed evaluation approach evolved from the policy direction for Beijing, the city is not unique in seeking to progress along the axis of human orientation, efficiency and sustainability and these goals can be found individually within the policy directives of many national and regional authorities internationally. The framework illustrated by Table 5 can therefore be used to assess measures together and as part of a policy bundle, then considering the design of future measures. Policymakers can adopt the framework as part of a policy assessment process of current measures (as here), for example, highlighting as part of policy review that some forms of equity are not met by their current demand management measures. The significance of that outcome to their design process will vary according to their local context and policy priorities. Consider the hypothetical case where EP3 is particularly important to the authority (achievement of an even distribution of benefits could be part of the stated policy priorities for the city or region). It becomes clear from use of the framework that none of the current policies are orientated towards that indicator. It is apparent from the framework, however, that currently policies are all highly targeted towards efficiency and the policy commitment to support efficiency is being achieved. The transparency provided concerning these outcomes assists by empowering the decision making process to prioritise, purposefully design and implement future demand measures towards the EP3 principle, where this aligns with their goals and jurisdiction. Where measures are proposed that do not support raising the distribution of benefits to the least advantaged spatial areas, the framework provides a reference to support the need for re-design. The framework may be particularly useful where there are a large number of measures in place and synthesising their orientation to the criteria is challenging otherwise. It can also be used in governing contexts where there are politically competing agendas and priorities within the decision making unit.

In terms of the input information needed for the framework, it is flexible in that either quantitative information or a mixture of quantitative and qualitative data may be used. The use of purely quantitative measures as inputs is the subject of a further paper. It is also worth noting that almost all instruments for “command-and-control” and market-based management instruments could be considered for implementation in the near future and to support the advanced transport management of Beijing, which will also form the basis for a further study.

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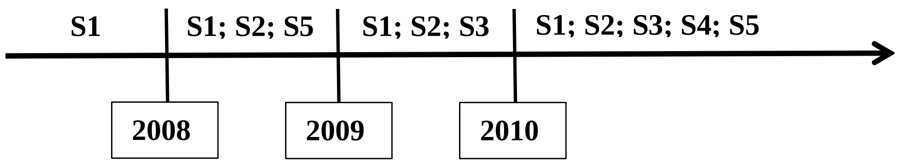

Figure 1 Applications of transport management policies over time

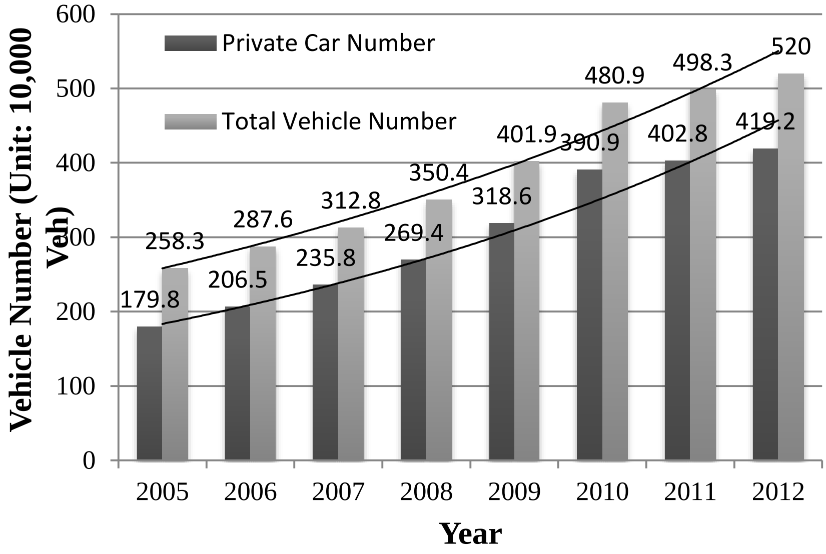

Figure 2. Annual variations of vehicles in Beijing municipality (2005-2012)

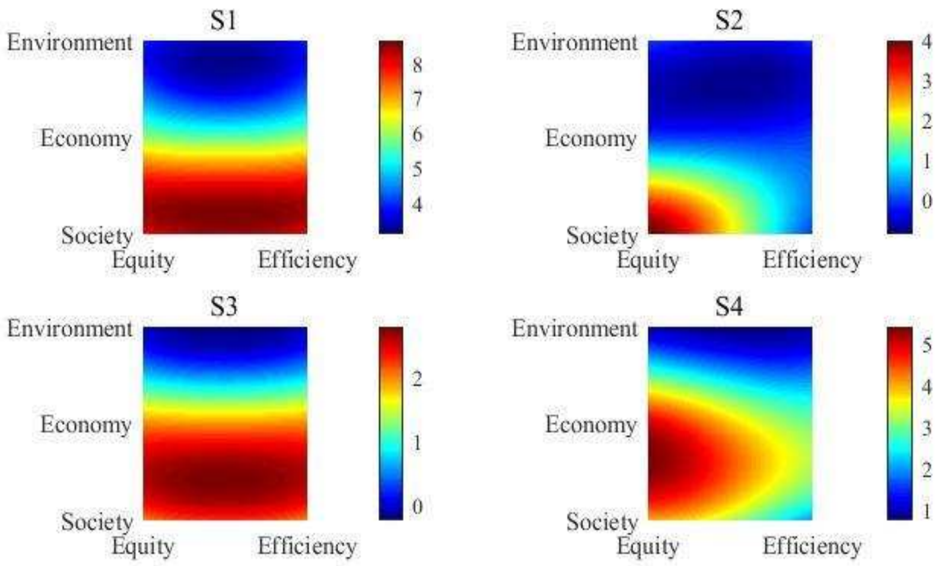

Figure 3. Heat maps in addition to the table 5

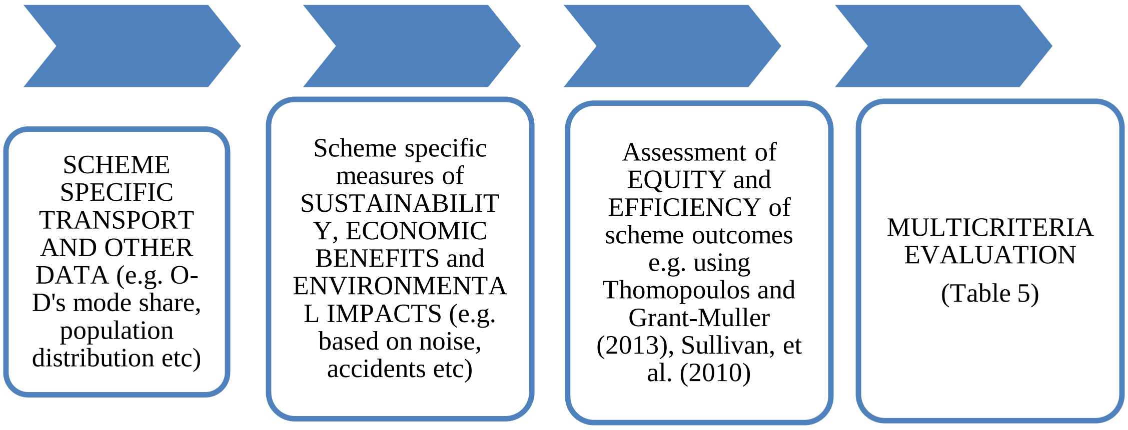

Figure 4. Summary process for evaluation of scheme impacts

Table 1 Summary of typical transport management measures studies implemented in Beijing

Measures	Literature(s)	Study area	Methodology	Major findings
Priority development of mass transit systems (S1)	Tiwari (2002)	Delhi	Statistical analysis	· An efficient bus system cannot be designed without taking care of slow vehicles (non-motorized vehicles, NMVs) on the road. · Planning for non-motorized transport and integrating it with the other modes of city transport is a prerequisite for creating sustainable transport systems, thus leading to sustainable cities.
	Goh et al. (2014)	Melbourne	Experimental microscopic traffic simulation	· The effects of bus priority act to reduce sideswipe and rear-end traffic conflicts and thus to improve road safety
	Currie, Sarvi and Young (2007)	Melbourne	Traffic micro-simulation modelling	· Despite a more comprehensive approach to measuring the benefits of bus and tram priority, road-space reallocation is difficult to economically justify in road networks where public transport usage is low and car usage high. · Strategies involving the balanced deployment of bus and tram priority measures (where the allocation of time and space to PT minimises negative traffic impacts) is shown to improve the overall management of road-space.
	Xu et al. (2010)	Beijing	Statistical analysis	· The governance evolution structures and practices provides a beneficial effect on Beijing road-based PT activity as a whole. It is found that about 7.1% of the total growth of Beijing road surface PT activity, on average over the period 1980-2005, is due to governance evolution.
Private car ownership control (S2)	Phang, Wong and Chia (1996)	Singapore	Review paper	· The car quota policy and its implementation in Singapore achieved its goals in controlling the numbers of cars and improving the quality of cars imported; · The policy also suffered from unintended consequences, (e.g. speculative activities) and proposed the creation of an asset market for vehicle licenses.

	Feng and Li (2013)	Shanghai, Beijing, Guangzhou	Review paper	· Although the three cities adopt different quota allocation mechanisms, their policy objectives are clear and similar. · Beijing puts more emphasis on equity, while Shanghai seems to focus on efficiency. Guangzhou combines the merits and shortcomings of both Shanghai and Beijing, yet it adds its own touch by putting a time limit on the licences of all vehicles.
	Chen and Zhao (2013)	Shanghai	Statistical analysis	· Respondents perceive the policy to be effective, but are moderately negative towards the policy nonetheless. However, they expect that others accept the policy more than they do; · Respondents also hold consistently negative perceptions about the affordability of the license, the effects on equity, and the implementation process.
	Yang et al. (2014)	Beijing	Statistical analysis	· The Beijing's vehicle registration lottery policy has had a significant effect on the number of vehicles sold; · The lottery policy might not decrease fuel consumption as much as one might expect; · The lottery has had the unintended consequence of allocating vehicles to people who clearly do not have the highest willingness to pay.
Staggered rush hour plan (S3)	Rosenbloom (1978)	-	Review paper	· Varying work hours does seem to relieve some forms of congestion in specific areas of high concentrations of employment. However, such plans require the continued cooperation of a significant percentage of the employers and employees within a given area to have much impact on either transit or highway peak-period congestion.
	Plane (1995)	-	Review paper	· If 10 percent of work trips were shifted outside of peak periods with the staggered work hours, total morning peak trips would reduce by 5 percent.
	Guo et al. (2015)	Beijing	Review paper	· The flexible work hours help to ease traffic pressure in rush hours
New charging	Hensher and King (2001)	Sydney central business district	Stated preference survey	· Investigation of the role of parking pricing and supply by time of day in whether to drive and park in the central business district (CBD). The change in CBD parking share attributable to supply by time of day is less than 3%, compared to 97% attributable to parking prices.

policies for parking (S4)	Rye and Ison (2005)	11 UK workplaces	Interview-based qualitative research	· Very few organisations have introduced parking charging, and those that have appear to be limited almost exclusively to the public sector and, within that, to hospitals and universities; · Parking charges can be implemented at workplaces, while their implementation is not simple
	Marsden (2006)	Great Britain	Review paper	· In many instances does not support, or provides evidence counter to, the assumption that parking restraint makes centres less attractive
	Mei et al. (2010)	Tongling City	Optimization	· Proposes a Probit-based curb parking model, and shows application in Tonglin City
Traffic restrictions based on the last digit of license plate numbers (S5)	Eskeland and Feyzioglu (1997)	Mexico City	Welfare economics	· Due to the tendency of motorists to acquire an additional car, the restriction based on the last digit of license plate numbers actually increases congestion and pollution in the long run.
	Davis (2008)	Mexico city	Data analysis	· No improvement according to the hourly data, and use of public transport has not increased; · Gasoline sales rise more than expected and so did air pollution.
	Han, Yang and Wang (2010)	-	Network equilibrium analysis	· Efficiency analysis and propose several lower bounds and upper bounds of the ratio between the system cost at the new user equilibrium with rationing and the original system cost at user equilibrium.
	Wang, Xu and Qin (2014)	Beijing	Statistical analysis	· The restriction policy in Beijing does not have significant influence on individuals' decisions to drive, as compared with the policy's influence on public transit. · The rule-breaking behavior is constant and pervasive, 47.8% of the regulated car owners didn't follow the restriction rules.
	De Grange and Troncoso (2011)	Santiago	Aggregates analysis	· The permanent restriction had no impact on the use of private cars while the additional restriction curtailed their use by 5.5%; · The pre-emergency restrictions had an effect on the ridership of the Metro but not on the bus network as alternatives to the use of private cars.

Table 2. Summary and impacts of selected transport management measures in Beijing

Item	Outline	Target	Type of Impacts							
			I1	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**
Priority development of mass transit systems (S1)	· Fast development and adjustment of urban space and transport structures; · Establish the social welfare importance of public transport; · Accelerate subway construction and expand the PT travel share; · Implementation of 'four priority' policies to improve the PT system (land use; investment; dedicated road lanes, fiscal support); · Scope of the structure and fare standards of PT tickets; · 28 specific solutions offered to relieve traffic congestion from the perspectives of "Managing, Building and Restricting".	· Prioritise PT infrastructure development; · A 'public-transport city' with an attractive mass transit system; · The social welfare role; · Traffic congestion mitigation based on PT and "1-1-2" plans for 2015.	√		√		√	√	√	√
Private car ownership control (S2)	· Continue to implement vehicle constraint measures; · The application process and use of the quota for private car and official business car buying.	· Constraint on the number of private car in the city of Beijing.	√	√	√		√	√	√	√
Staggered rush hour plan(S3)	· All parties and governmental organizations, social groups, public units, state-owned enterprises and urban collective-owned enterprises subordinate to Beijing should use a new work schedule; · The working hours of Beijing's commercial enterprises, public units and social groups subordinate to the central government, schools, hospitals and department stores in Beijing will not change.	· Improving the traffic environment and alleviating rush hour traffic congestion.			√	√	√			
New charging policies for parking(S4)	· Specification of new charging levels for parking based on three defined area types in Beijing; · Specification of new charges standard for parking in daytime (7:00am-21:00pm) based on three defined area types in Beijing.	· Mitigate traffic congestion in some key business areas; · Reduce parking on roads; · Optimize traffic conditions.	√				√	√	√	

Traffic restrictions based on the last digit of license plate numbers(S5)	· During 07:00am and 8:00pm, private cars and official business inside the 5th ring road (inclusive) of Beijing municipality should not be driven on public roads for one day per week; · Every three months, the group of cars that could not use public road space for a certain weekday would rotate; · Traffic permits for entering Beijing are needed for non-Beijing passenger service vehicles, and Non-Beijing passenger service vehicles heading for Beijing and with traffic permits to entering Beijing will be prohibited to run within the 5th Ring Road (inclusive) from 7:00am to 9:00am and from 17:00pm to 8:00pm on workdays.	· Mitigate traffic congestion; · Improve air quality.					√		√	√

Notes: I1: vehicle ownership; I2: vehicle type; I3: route change; I4: time change; I5: mode shift; I6: destination change; I7: trip generation; I8: land use changes.

Table 3. Trips with respect to modes at different years (Unit: Million journeys per day)

Year	Total number of average daily trips	Road surface PT	Subway	Car	Cycling	Population	Average number of daily trips per car	Average number of daily trips per person
2005	20.15	4.86	1.15	6.01	6.11	15.38	3.34	1.31
2007	22.75	6.27	1.59	7.42	5.23	16.33	3.15	1.39
2008	26.37	6.41	1.82	7.64	4.62	16.95	2.84	1.56
2009	27.46	7.94	2.75	9.34	4.97	17.55	2.93	1.56
2010	29.04	8.18	3.35	9.93	4.76	19.61	2.54	1.48
2011	28.73	8.11	3.95	9.48	4.32	20.19	2.35	1.42
2012	30.33	8.28	5.09	9.9	4.22	20.69	2.36	1.47

Table 4. Peak trips differences with respect to modes

Year/Mode	Average travel distance (Unit: Km)				Average travel time (Unit: Min)							
					Morning peak (7am-8am)				Evening peak (5pm-6pm)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
2009	7.27	14.84	10.78	2.95	54.4	68.31	36.43	23.04	55.41	62.72	35.78	24.87
2010	9.6	16.9	9.3	3.8	60.7	73.1	32.9	21.4	66.4	74.8	38.9	23
2011	10.3	16.5	11.4	4.7	56	58	35	17	57	51	39	22
Year					Average travel speed (Unit: Km/Hour)							
					Morning peak (7am-8am)				Evening peak (5pm-6pm)			
					M1	M2	M3	M4	M1	M2	M3	M4
2009					8.02	13.03	17.75	7.68	7.87	14.20	18.08	7.12
2010					9.49	13.87	16.96	10.65	8.67	13.56	14.34	9.91
2011					11.04	17.07	19.54	16.59	10.84	19.41	17.54	12.82

Note: M1: Road surface public transport; M2: Subway; M3: Car; M4: Cycling.

Table 5. Multi-criteria evaluation of the transport management measures in Table 2

Sustainability / Index		Society				Economy			Environment		
		So1	So2	So3	So4	Ec1	Ec2	Ec3	En1	En2, En4	En3
Equity*	EP1	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$ $S5_{+,-}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,-}$ $S5_{+,/}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,/}$ $S5_{+,-}$	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$ $S5_{+,/}$	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$ $S5_{+,-}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,+}$ $S5_{+,/}$	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$ $S5_{+,-}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,+}$ $S5_{+,/}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,/}$ $S5_{+,/}$	$S1_{+,-}$ $S3_{+,/}$ $S4_{+,/}$ $S5_{+,/}$
	EP2	$S1_{+,+}$ $S2_{+,+}$	$S1_{+,+}$ $S2_{+,+}$	$S1_{+,+}$ $S2_{+,+}$	$S1_{+,+}$ $S2_{+,+}$	$S1_{+,+}$ $S2_{+,/}$	$S1_{+,+}$ $S2_{+,/}$	$S1_{+,+}$ $S2_{+,-}$	$S1_{+,+}$ $S2_{+,/}$	$S1_{+,+}$ $S2_{+,/}$	$S1_{+,-}$ $S2_{+,/}$
	EP4	$S4_{+,+}$	$S4_{+,-}$	$S4_{+,/}$	$S4_{+,+}$	$S4_{+,+}$	$S4_{+,/}$	$S4_{+,+}$	$S4_{+,/}$	$S4_{+,/}$	$S4_{+,/}$
Efficiency	ET1	$S1_{+,+}$ $S5_{+,-}$	$S1_{+,+}$ $S5_{+,/}$	$S1_{+,+}$; $S5_{+,-}$	$S1_{+,+}$ $S5_{+,/}$	$S1_{+,+}$ $S5_{+,-}$	$S1_{+,+}$ $S5_{+,/}$	$S1_{+,+}$; $S5_{+,-}$	$S1_{+,+}$ $S5_{+,/}$	$S1_{+,+}$ $S5_{+,/}$	$S1_{+,-}$ $S5_{+,/}$
	ET2	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,-}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,/}$	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,+}$	$S1_{+,+}$ $S3_{+,+}$ $S4_{+,+}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,+}$	$S1_{+,+}$ $S3_{+,/}$ $S4_{+,/}$	$S1_{+,-}$ $S3_{+,/}$ $S4_{+,/}$

Note: *We remove the EP3, EP5 and EP6 from the table considering that they are not applicable here

Appendix I

Abbreviations

BMCT	Beijing Municipal Commission of Transport (www.bjjtw.gov.cn)
BMCHURD	Beijing Municipal Commission of Housing and Urban-Rural Development (www.bjjs.gov.cn)
BMCC	Beijing Municipal Commission of Commerce(www.bjmbc.gov.cn)
BMCDR	Beijing Municipal Commission of Development and Reform (www.bjpc.gov.cn)
BTMB	Beijing Traffic Management Bureau (www.bjjtgl.gov.cn)
BMBS	Beijing Municipal Bureau of Statistics (www.bjstats.gov.cn)
BTRC	Beijing Transportation Research Centre (www.bjtrc.gov.cn)
GDP	Gross Domestic Product
NBSC	National Bureau of Statistics of China (www.stats.gov.cn)
PGBM	The People's Government of Beijing Municipality (www.beijing.gov.cn)
PT	Public Transport
WCED	World Commission on Environment and Development